the activity-dependent regulation of dendritic voltage-activated ion channels [9]. Activity-dependent plasticity of dendritic synaptic integration must therefore be considered to contribute to information storage in the brain.

It is now clear that dendritic spikes are generated in many regions of the dendritic tree of single neurons. The challenge for the future is to dissect the role played by these integration compartments in shaping the action potential output of neurons, and how they are engaged when neurons operate in the working brain. Advances in imaging and *in vivo* dendritic recording techniques will help answer this question. Such information will be essential to establish a link between neuronal computation and neural circuit function. Nevertheless, the idea that neurons function as simple point processes has passed, and we must consider dendritic synaptic integration as an important determinant of neural circuit function.

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MRC Laboratory of Molecular Biology, Hills Road, Cambridge CB2 0QH, UK.
E-mail: srw@mrc-lmb.cam.ac.uk

Correspondences

Visual distortion of a limb modulates the pain and swelling evoked by movement

G. Lorimer Moseley[1,2], Timothy J. Parsons[1] and Charles Spence[3]

The feeling that our body is ours, and is constantly there, is a fundamental aspect of self-awareness [1]. Although it is often taken for granted, our physical self-awareness, or body image, is disrupted in many clinical conditions [2] (see also [3] for a list of such conditions). One common disturbance of body image, in which one limb feels bigger than it really is, can also be induced in healthy volunteers by using local anaesthesia or cutaneous stimulation [4]. Here we report that, in patients with chronic hand pain, magnifying their view of their own limb during movement significantly increases the pain and swelling evoked by movement. By contrast, minifying their view of the limb significantly decreases the pain and swelling evoked by movement. These results show a top-down effect of body image on body tissues, thus demonstrating that the link between body image and the tissues is bi-directional.

Ten right-handed patients with chronic pain and dysfunction of one arm participated in our study (see Table S1 in the Supplemental data available on-line). Patients watched their own arm while they performed a standardised repertoire of ten hand movements, at a set speed and amplitude, and in randomised and counterbalanced order. Four randomised conditions involved different ways of looking at the arm: Control (looking without any visual manipulation); Clear (looking through binoculars with no magnification); Magnified (binoculars with 2x magnification); and Minified (inverted binoculars).

The patients' pain (on a 100 mm visual analogue scale) was worse after movements than it was before, but the extent to which it was worse depended on the type of visual input. That is, the increase in pain was greatest when participants viewed the magnified image of their arm during the movements (mean ± SD increase = 41 mm ± 15 mm) and least when they viewed the minified image of their arm during the movements (19 mm ± 18 mm; Figure 1). Swelling — the circumference of the fingers, relative to the unaffected hand — also increased less when participants watched a minified image of their arm during movements than when they watched a magnified image ($p < 0.01$), or when they viewed their limb as it normally appears ($p < 0.02$). Recovery to pre-task pain was slowest when the visual input during movements had been magnified but quickest when it had been minified (Figure 1B; see Supplemental data for statistics). Two patients terminated movements in every condition because of intolerable pain and two other patients terminated movements because of intolerable pain in the magnified condition only (Figure S3 in the Supplemental data).

These results support the hypothesis that making a limb look bigger increases the pain and swelling evoked by movement. Remarkably, they also demonstrate that making a limb look smaller *decreases* the pain and swelling evoked by movement. These findings are not predicted by the current view that emphasises a bottom-up relationship between the tissues and body image, whereby aberrant or absent input from the former causes distortions in the latter [4].

How might distorting the view of the limb modulate pain and swelling? One possibility relates to the visual enhancement of touch, which is probably mediated by visuotactile cells in the parietal cortex. Notably, magnifying the view of the area being touched further enhances tactile acuity [5] and alters somatosensory cortex (S1) organisation [6].

Might a different effect occur in patients with chronic pain? Pain emerges from the flow and integration of neural activity within a distributed network of brain areas, usually including the primary

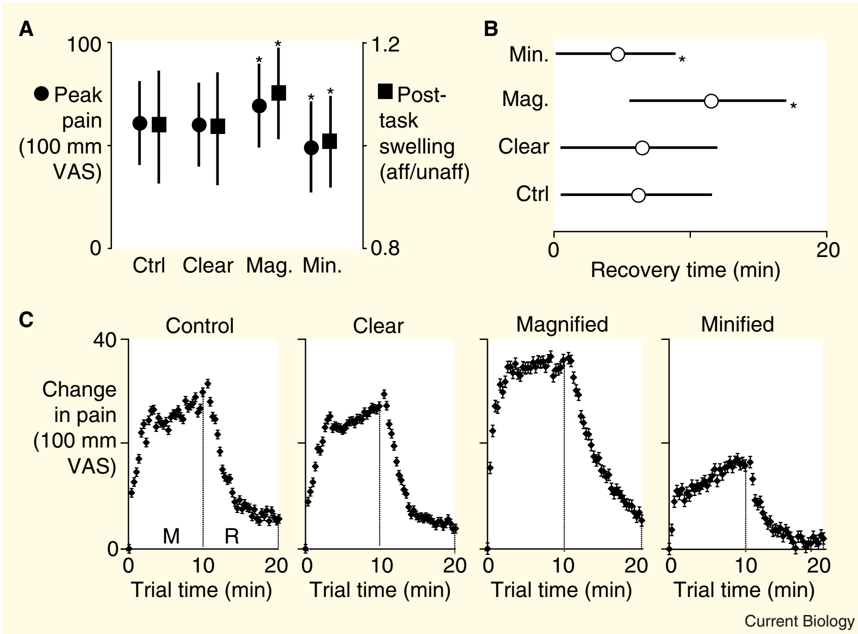

Figure 1. Distortion of limb size affects pain.

(A) Mean and standard deviation (SD, error bars) peak in pain (on a 100 mm visual analogue scale, VAS; circles) during, and swelling (squares) after a standard set of movements performed with four types of visual input. Swelling was the average circumference of fingers 2–4 of the affected hand expressed as a proportion of the same measure obtained from the unaffected hand. (B) Time to recover: mean and SD time to return to pre-task pain levels after ten minutes of movements. Asterisk denotes different to both clear and control conditions (* = $p < 0.02$). (C) Pain over time: mean and SEM (error bars) *increase in* pain while participants moved — for the first ten minutes (M) or until they found the pain to be intolerable — and then for ten minutes recovery (R).

somatosensory cortex area S1. When pain persists, this network is thought to be upregulated and endogenous antinoceptive mechanisms downregulated (see [7] for review), such that even imagined movements can increase pain and swelling [8]. Perhaps the increase in S1 activation imparted by magnifying the view of the limb triggers this upregulated pain system. Another possible explanation is that the conflict between vision and proprioceptive feedback increases pain and swelling, which has been proposed before [9], although the current experimental evidence is equivocal.

The clinically profound result of our work is that making the limb look smaller than it really is (by viewing it through a minifying lens) decreases the pain and swelling evoked by movement of that limb. Perhaps this effect relates to a reduced sense of ownership over the limb. Ramachandran and Altschuler's recent anecdotal report that healthy subjects feel like a limb doesn't belong to them anymore when they watch it through a minimising lens [10], and that illusory ownership over an artificial limb induces a drop in skin blood flow in the 'disowned' limb [3], would seem to support that possibility. The obvious clinical implication is that if manipulation of visual input can reduce the pain and swelling evoked by movement, it may assist in the rehabilitation of acute and chronic physical, neurological and psychiatric disorders associated with certain body image disturbances.

Regardless of the mechanism(s) underpinning the effect, modulation of pain and swelling via distortion of vision establishes that the link between pain and tissue condition on the one hand, and distorted body image on the other, is a bi-directional one. The result also suggests that the manipulation of visual input might lead to novel clinical applications, should the reduction in swelling and pain following the viewing of the affected limb through a minifying lens demonstrated here be shown to lead to longer-term beneficial effects in future research.

Supplemental Data

Supplemental data are available at http://www.current-biology.com/supplemental/S0960-9822(08)01259-1.

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[1]Department of Physiology, Anatomy & Genetics, University of Oxford, UK. [2]Prince of Wales Medical Research Institute, Sydney, Australia. [3]Crossmodal Research Laboratory, Department of Experimental Psychology, University of Oxford, UK.
E-mail: lorimer.moseley@gmail.com